Peer Review
Experimental Toxicology Division
NHEERL

EMERGING ISSUES

Response to the World Trade Center Disaster - Chemistry and Toxic Respiratory Effects of WTC Fine Particulate Matter

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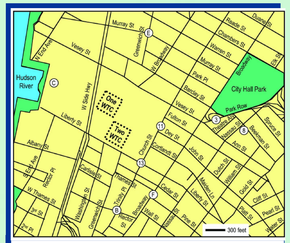
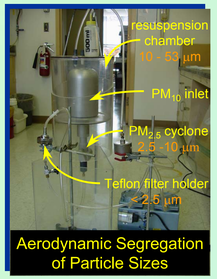
Environmental Issue and Objectives

- Burning and collapse of the WTC on 9/11/01 released tons of particulate matter (PM) into the local environment.
- $PM_{2.5}$ (< 2.5 μ MMAD) is associated with cardiovascular and respiratory disease, but the chemical properties and relative toxicity of WTC $PM_{2.5}$ were unknown.
- Our objectives were to evaluate WTC $PM_{2.5}$ chemistry and potential toxicity relative to well-characterized reference $PM_{2.5}$ samples.
- These studies contributed to the assessment of the short-term health risk of exposure to WTC PM in the immediate aftermath of the disaster.


Bulk Settled Dust
Lioy et al., *EHP* 2002



Sample Collection Sites
numbers: 9/12/01 letters: 9/13/01



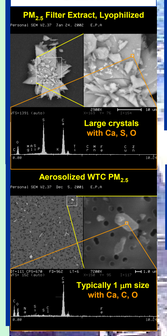
Aerodynamic Segregation of Particle Sizes

CHEMICAL ANALYSIS OF WTC $PM_{2.5}$

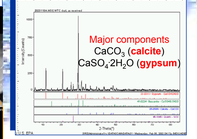
McGee et al., *Environ Health Perspect* 111:972-980, 2003

SOLID SAMPLES

SEM



X-Ray Diffraction



Elemental Analysis
Neutron Activation Analysis
X-Ray Fluorescence

Carbon
OC, EC, CC fractions

AQUEOUS EXTRACTS

pH: 8.88 – 10.00
endotoxin: < 0.25 EU/mg

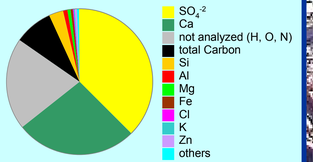
Elemental Analysis
ICP-AES
ICP-MS

Ion Chromatography

- Sulfate totally H_2O-soluble (closely matches solid samples)
- Ca mostly H_2O-soluble
- Variable solubility of other elements.

WTC $PM_{2.5}$ Elemental / Ion Content

XRF, carbon analysis



- High levels calcium (27%) and sulfate (38%)
- Si, Al, Mg, Fe in proportions found in cement, concrete.
- Lower levels of transition & heavy metals, carbon.

PULMONARY TOXICITY IN CD-1 MICE

Gavett et al., *Environ Health Perspect* 111:81-991, 2003

RELATIVE TOXICITY

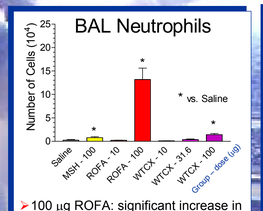
Responses measured 1 day after airway aspiration of 10, 31.6, 100 μg

WTC $PM_{2.5}$
Pooled sample "X" composed of sites 8, 11, 13, B, C, E, F

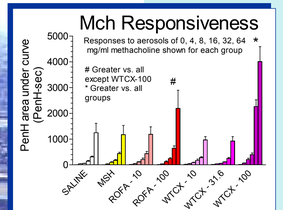
ROFA $PM_{2.5}$
Residual oil fly ash – high toxicity

MSH $PM_{2.5}$
Mt. St. Helens dust – low toxicity

Saline Vehicle



- 100 μg ROFA: significant increase in neutrophils (31% of total BAL cells).
- 100 μg pooled WTC $PM_{2.5}$ – much lower response (7% total BAL cells).
- Lung pathology findings consistent.



- 100 μg ROFA: hyperresponsive to Mch compared with saline control group.
- 100 μg WTC $PM_{2.5}$ – hyperresponsive vs. all groups including toxic ROFA.

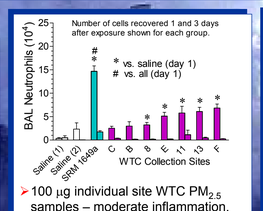
DEPENDENCE ON LOCATION

Responses measured 1 and 3 days after airway aspiration of 100 μg

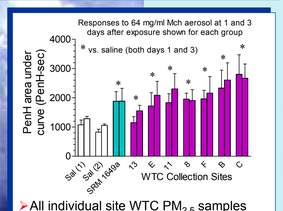
WTC $PM_{2.5}$
Responses to individual sites tested: 8, 11, 13, B, C, E, F

SRM 1649a $PM_{2.5}$
Washington DC ambient air sample from NIST

Saline Vehicle



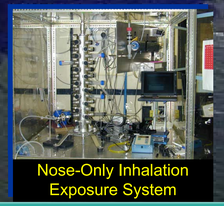
- 100 μg individual site WTC $PM_{2.5}$ samples – moderate inflammation, less than response to SRM 1649a.
- Lung pathology findings consistent (focal bronchiolar inflammation).
- Responses greatly reduced at day 3.



- All individual site WTC $PM_{2.5}$ samples caused hyperresponsiveness to Mch compared with saline control group, but not compared with SRM 1649a.
- Responses stable at day 3.

UPPER AIRWAYS RESPONSES

Responses measured 1, 3, and 6 days after nose-only inhalation exposure to air or WTC $PM_{2.5}$ (*site 3*)
10.6 mg/m³, 5 hr exposure.
Total respiratory tract dose: **~14 μg**
(estimate based on Freijer et al. 1999. Multiple path particle deposition model v. 1.11 (CIIT, RIVM), using rat model).


Nose-Only Inhalation Exposure System

- Some increases in airflow obstruction in individual mice measured immediately after exposure, but no group effect.
- No effects on responsiveness to Mch or lung pathology; some increases BAL cells.
- Minimal-mild rhinitis (mucosal neutrophils), but only in 4/8 exposed mice, and only 1 day post-exposure; no epithelial cell injury.

Estimated WTC $PM_{2.5}$ Concentrations

necessary to produce doses in people equivalent to mouse doses

Total Mouse Deposited Dose (μg)	Mouse / Human Dose per TB Surface area (μg/m²)	WTC $PM_{2.5}$ concentration (μg/m³)
10	97	**42**
31.6	307	**134**
100	973	**425**

Assumptions:
- Critical dose metric: dose per tracheobronchial surface area.
- Mouse dose spread evenly over respiratory tract
- 30 yr 5'10" male, FRC = 3300 ml, oronasal breather 30 L/min.
- Model particles: density = 1 g/cc, 1 μm, σg = 2.5 (Freijer et al. 1999, MPPD v 1.11)
- Inhaled over 8-hr workshift with no respiratory protection.

Conclusions

- WTC $PM_{2.5}$ is alkaline and composed of a high content of Ca and SO_4. Known respiratory irritants (calcite and gypsum) are major components. Sampling site was not related to chemistry or biological responses, suggesting WTC $PM_{2.5}$ is fairly homogeneous.
- We estimate people exposed to ~ 425 μg/m³ WTC $PM_{2.5}$ for 8 hours without respiratory protection would get a dose comparable to the 100 μg dose in mice, which caused pulmonary inflammation and hyper-responsiveness to Mch. $PM_{2.5}$ concentrations immediately after the WTC collapse are unknown, but it is likely that levels were this high.
- We estimate that healthy individuals exposed to lower concentrations of WTC $PM_{2.5}$ (< 130 μg/m³ for 8 hr) should not experience adverse effects, although especially sensitive individuals (e.g. asthmatics) may experience effects at lower doses.

Impact / Future Directions

- This is the first study to show that WTC $PM_{2.5}$ can cause toxic respiratory effects in animals at relatively high doses which could have occurred in people exposed during and after the collapse of the towers. Notably, firefighters present at the collapse of the WTC towers had significantly increased levels of cough and airway hyper-responsiveness (Prezant, *N Engl J Med* 347:806, 2002).
- These studies provide essential information on the chemistry and respiratory toxicity of WTC $PM_{2.5}$. They have contributed to EPA's health risk assessment of pollutants derived from the WTC.
- Valuable lessons were learned in dealing with rapidly-developing and/or acute environmental issues. The availability of well-characterized reference samples and a comprehensive array of chemical analyses and rapid bioassays are necessary to characterize acute toxicological risks of novel environmental contaminants.


Studio Libeskind Wedge of Light

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SOLVING AGENCY PROBLEMS